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ACS-201

Final Report

ALTERNATE CONCEPTS STUDY EXTENSION

Volume I

EXECUTIVE SUMMARY

Contract NAS 8-26362

Prepared for George C. Marshall Space Flight Center By
Manned Space Programs, Space Systems Division

LOCKHEED MISSILES & SPACE COMPANY
SUNNYVALE CALIFORNIA

FOREWORD

This is the final report of a four-month extension of the Phase A Study of Alternate Space Shuttle Concepts (NAS 8-26362) by the Lockheed Missiles & Space Company (LMSC) for the National Aeronautics and Space Administration, George C. Marshall Space Flight Center (MSFC). This study extension, which began on 1 July 1971, was to study two-and-one-half stage, stage-and-one-half, and SRM interim booster systems for the purpose of establishing feasibility, performance, costs, and schedules for these system concepts.

The final report consists of three volumes (6 books) as follows:

- Volume I – Executive Summary
- Volume II – Concept Analysis and Definition
  - Part 1 – O4OA System
  - Part 2 – One-and-One-Half Stage System
  - Part 3 – SRM Booster
  - Part 4 – Avionics
- Volume III – Cost Analysis

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Section 1
INTRODUCTION

The Lockheed Alternate Space Shuttle Concepts Study reflects a continuing company participation with NASA in the definition of advanced space transportation system concepts, extending back through the NASA Integral Launch and Reentry Vehicle studies to the early 1960s. The present study was initiated in July 1970 under the direction of NASA-MSFC specifically to examine the stage-and-one-half concept and other alternatives to the two-stage fully reusable configuration, which in the current environment appears to require too large an investment.

The current four-month Alternate Concepts Study Extension considers two main program alternatives:

- Phased booster development with an interim solid rocket motor (SRM) cluster preceding the reusable booster
- Phased orbiter development in a Mark I/Mark II configuration, with phased avionics, vehicle subsystems, thermal protection system, and J-2/J-2S engines evolving to the full-performance Mark II with the HiP_c engine.

The national interest in Space Shuttle stems from its potential ability to capture the full spectrum of projected missions during the late 1970s and 1980s, and to generate new traffic in extended space flight beyond the present Saturn/Apollo/Skylab programs. The objective of the ACS Extension study activity is to provide NASA with the basis for selection of a Space Shuttle concept that:

- Strikes a balance between investment costs and recurring operations costs
- Accomplishes timely availability of the system
- Meets the funding constraints

The variety of alternate concepts proposed, and the design variations within concepts, generate technical issues that are difficult to resolve. An approach to maintaining

order in the evaluation logic is suggested in Fig. 1-1, which segregates elements of the concept selection into levels and areas of activity as follows:

- Program Issues - selection at the decision level
- Program Alternatives - evaluation at the level of program plans and definition
- Design Approaches - technical definition at the design level
- Technical Issues - analysis at the trade study level

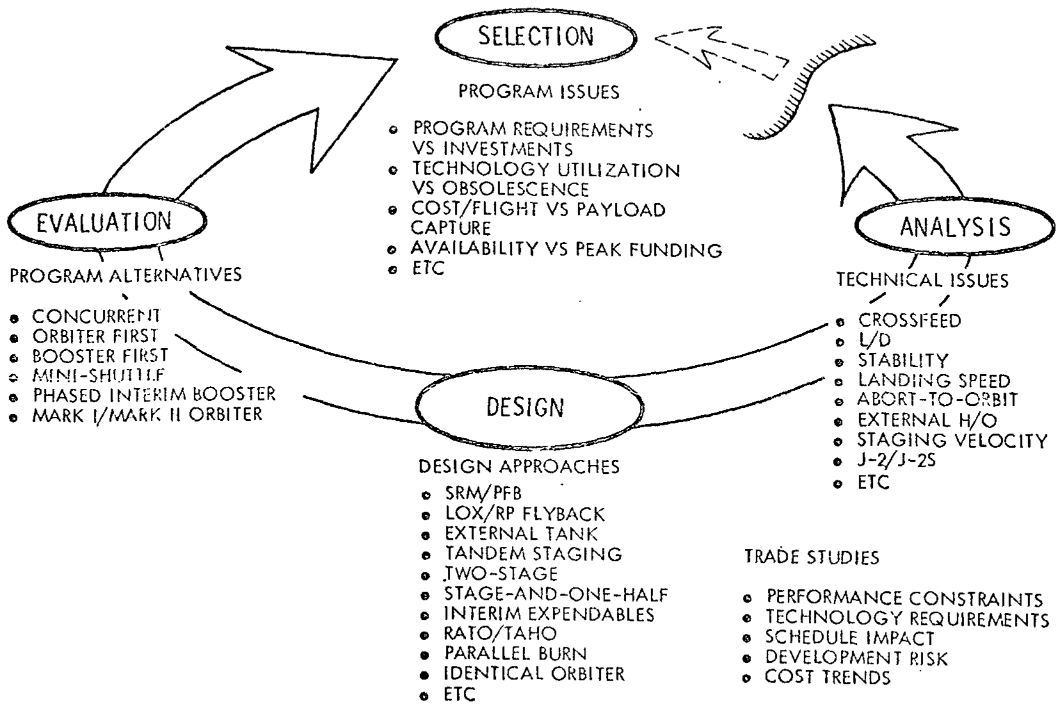


Fig. 1-1 Concept Selection Logic

Resolution of technical issues at the design level progressively eliminates alternative design approaches and program alternatives leading to selection at the decision level.

Within the study scope, three principal program alternatives were considered, each with an appropriate selection of design approaches:

- Concurrent Development
  - Two-Stage Fully Reusable
  - Stage-and One-Half
- Phased Booster Development
  - Interim SRM Booster
  - Stage-and-One-Half Conversion
- Phased Orbiter Development
  - Concurrent Flyback LOX-RP Booster
  - Concurrent SRM Booster

In the recently completed initial phase of the study summarized in the 4 June 1971 Final Report, effort focused on concurrent development, in which all program elements were pursued concurrently toward earliest achievement of low-cost operations. In the ACS Extension, Fig. 1-2, the two-stage and stage-and-one-half baseline concepts were updated in response to changing requirements and maintained as a basis of comparison. In this assessment, the two-stage fully reusable baseline system is preferred because it provides the most favorable potential for payload capture and extended space flight through its lowest recurring cost per flight, and at the same time it generates a large potential flow of technology into national economic development objectives. However, its large investment outlay for development and production and its peak funding profile are not compatible with apparent funding constraints. The stage-and-one-half design approach has many features and attains many of the objectives of the concurrent development alternative within funding profile constraints and remains a viable alternative. These technical and program definition studies provide the basis and point of departure for the Alternate Concepts Study Extension.

The span of effort starting 1 July 1971 and extending to the 1 September Interim Review considered phased booster development with large solid rockets (SRMs) as an interim expendable booster configuration and an external tank reusable orbiter designed for ultimate application with a cryogenic heat sink reusable booster. By direction, the

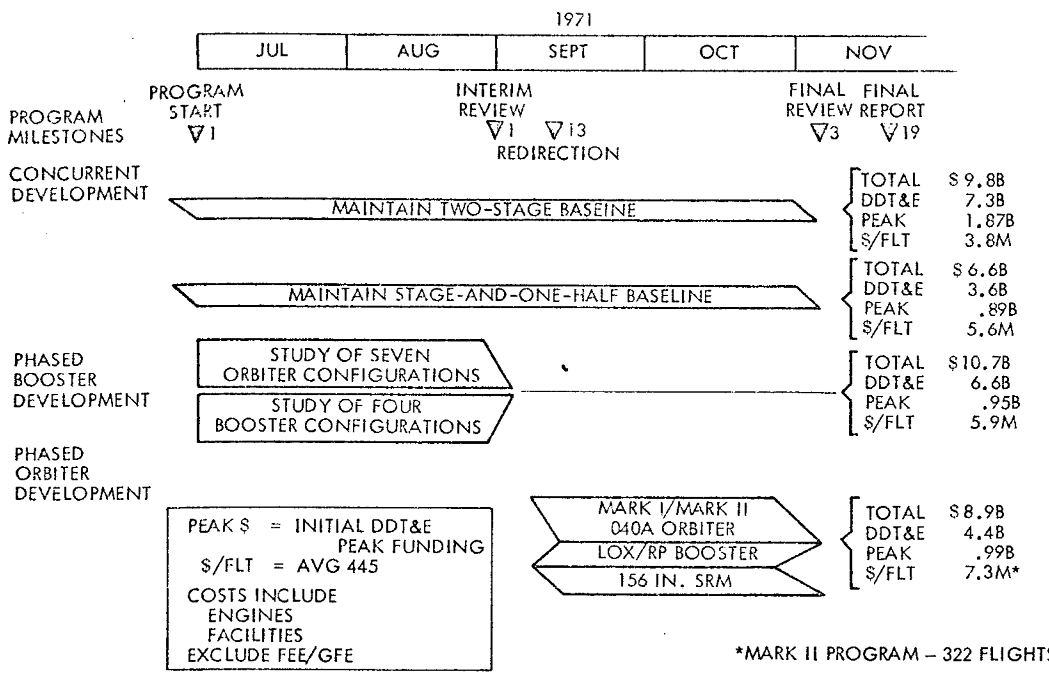


Fig. 1-2 Alternate Concepts Study Extension

reusable flyback booster characteristics were derived by scaling laws based on the Phase B Final Reports of other NASA contractors. This approach benefits technically in smaller orbiter size, and in development flexibility, through the use of large external propellant tanks. The interim configuration recommended on 1 September 1971, illustrated in Fig. 1-3, is based on a single orbiter development with 15 ft by 60 ft payload bay and full performance in interim and final configurations.

The phased interim SRM booster alternative suppresses peak annual funding to the target $1.0 billion level; however, the interim booster is a dead-ended development that contributes to higher total program cost as well as average cost per flight. The characteristic second funding peak associated with reusable booster development may prove a more difficult problem than the initial peak, and high interim operations cost delays payload capture potential of the system. On balance, the overall assessment appears negative for this program alternative. A similar approach based on conversion of an interim stage-and-one-half configuration, with delayed reusable booster development has essentially the same two peak funding characteristics with no net savings in total program cost.

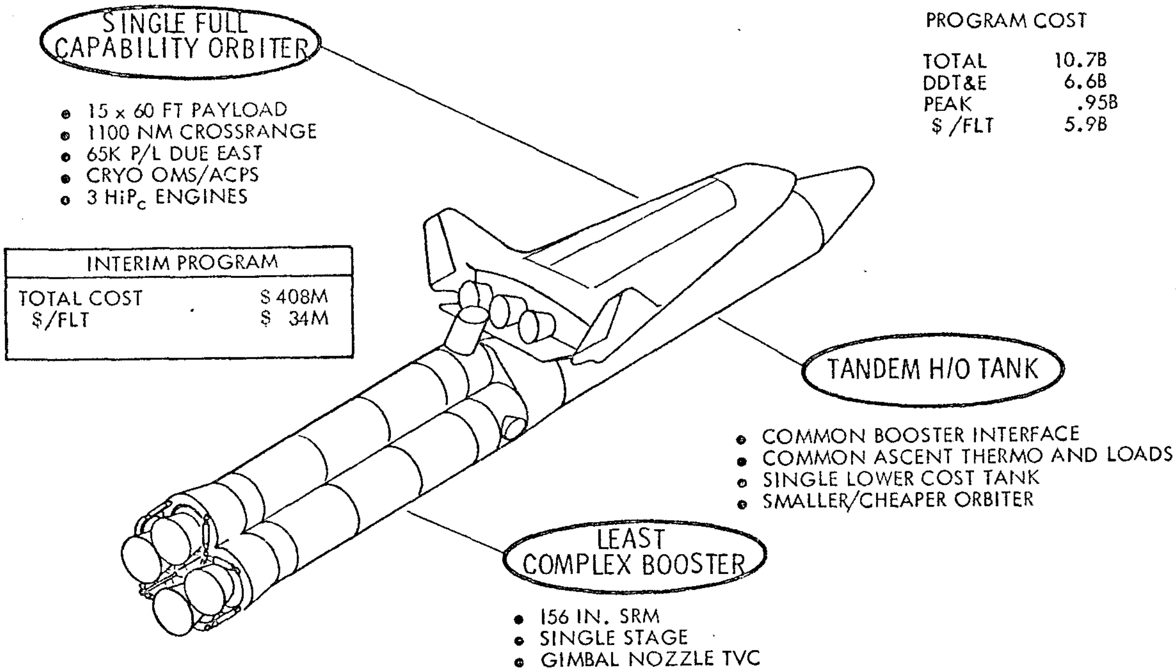


Fig. 1-3 Recommended Interim Configuration

Following the 1 September Interim Review, emphasis shifted to Phased Orbiter Development with reduced performance in a Mark I configuration followed by growth to Mark II capability five years into the operations program, while maintaining concurrent development of a flyback reusable LOX-RP booster based on F-1 engine technology. Phased application of primary rocket engines, J-2/J-2S in Mark I, leading to the HiP_c engine in Mark II, along with phased avionics and orbiter subsystem development serves to suppress peak annual funding requirements. Options for straight-through development with either the J-2S or the HiP_c engine alone were also considered. The recommended system configuration at the 3 November Final Review is illustrated in Fig. 1-4, utilizing the MSC 040A geometry with a single load-bearing H/O tandem external tank.

With the booster information provided by NASA, an acceptable funding profile was obtained for the recommended concept utilizing J-2S in Mark I and converting to HiP_c in Mark II five years into the program. The benefits of phased subsystems in

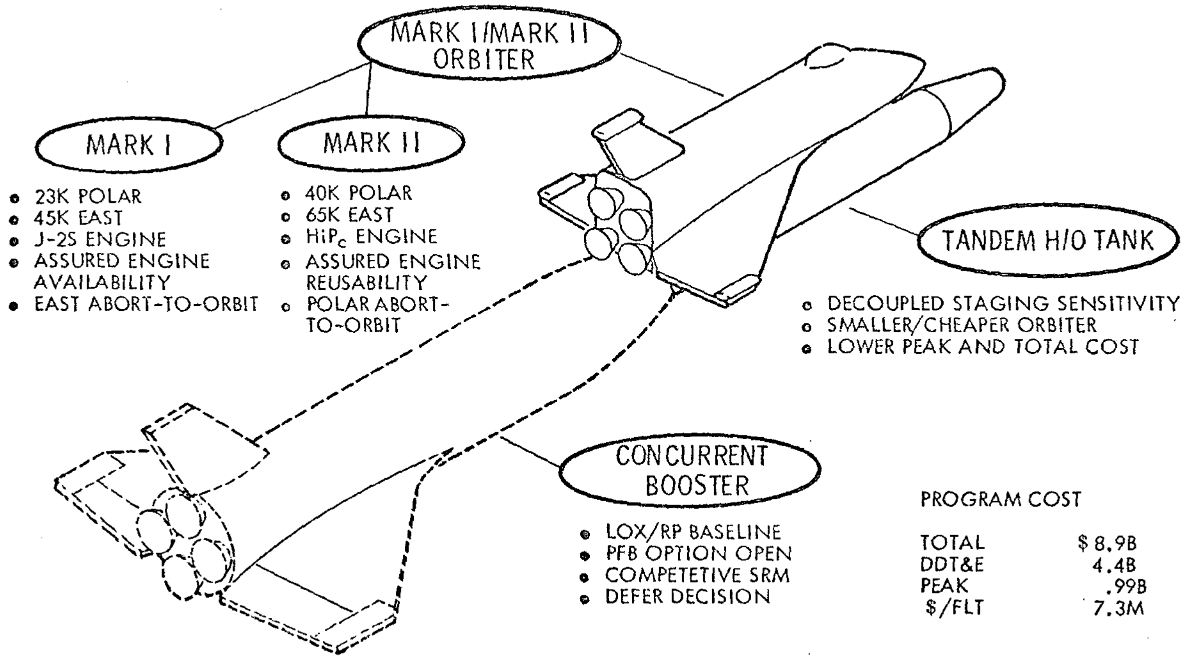


Fig. 1-4 Recommended Mark I/Mark II Configuration

suppressing peak funding derive from development and test hardware phasing rather than from production hardware phasing over the scheduled five-year gap between Mark I and Mark II. In effect, this gap implies holding open the Mark II design freeze indefinitely and incurs substantial risk of overdevelopment that is difficult to price, along with cost risks in deactivation and reactivation of facilities and workforce in manufacture and assembly.

A recommended alternative development approach is to complete manufacture and major subassemblies of all orbiter airframes, with final assembly of the two initial airframes to completion in the Mark I configuration, followed by a continuous modification program for updating and completion from storage as needed to the Mark II configuration, paced by the traffic projection. Considering booster integration and other program aspects, a significant cost reduction would be achieved with straight-through development using the RSI thermal protection system and either the J-2S or HiP_c engine alone.

In completing the second part of the study extension, the SRM booster work was continued at a low level to define a low-cost alternative comparable to the tandem pressure-fed ballistic recoverable concept, and the stage-and-one-half concept analysis was updated in response to changing guidelines and requirements to maintain a current alternative baseline configuration.

In summary, resolution of technical issues by design and analysis at the concept level among alternative design approaches has confirmed the feasibility of several design approaches for phased orbiter development, phased booster development, and concurrent development. Among the program alternatives evaluated, the overall balance with program issues favors a phased orbiter development approach to achieve timely availability of the system within projected funding constraints, and at the level of technology and sophistication that can be afforded as time progresses.

Section 2
CONCURRENT DEVELOPMENT

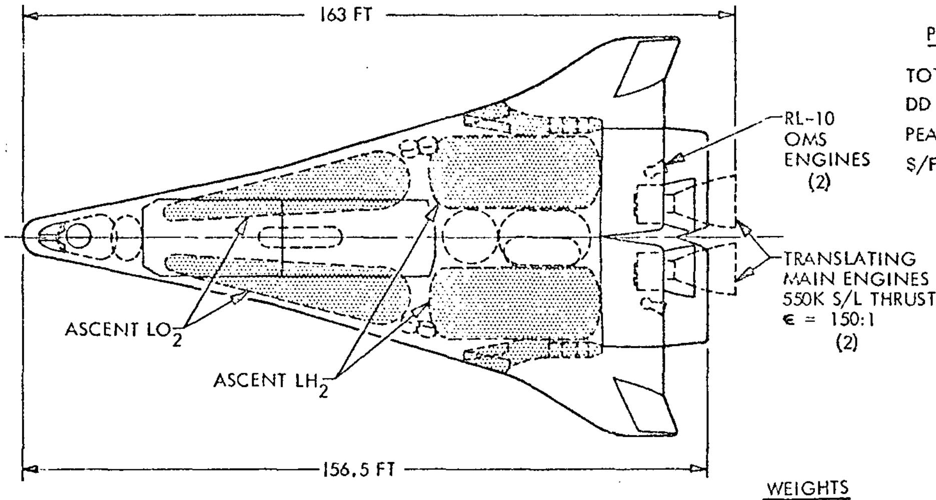
The concurrent development approach treated in the ACS Final Report, 4 June 1971, responded to the Phase B - Definition Phase Guidelines with FMOF on 1 April 1978 and a 72-month overall program span starting 1 April 1972. In the LMSC baseline program, three orbiter vehicles enter horizontal flight test prior to FMOF, FHF is scheduled for 1 February 1976, and two of the flight test vehicles enter vertical incremental flight test starting 1 June 1977. The development approach has final assembly at Palmdale, horizontal flight test at Edwards AFB, and launch operations at KSC.

TWO-STAGE FULLY REUSABLE APPROACH

The two-stage fully reusable concept illustrated in Fig. 2-1 is based on an advanced HiP_c ICD engine with advanced technology subsystems throughout. All propellant tankage is internal, and both orbiter and booster are concurrent single-thread developments leading to early realization of lowest recurring operations cost. This design approach on concurrent development provides the highest potential for payload capture and growth in utilization of space, meets all performance requirements for NASA or DoD missions, and achieves the lowest cost per flight. Use of advanced technology effectively removes the prospect of obsolescence and provides a large potential fallout of technology into national economic development. Its large investment outlay in DDT&E funding and peak annual funding rate of $1.87 billion appear incompatible with funding constraints in the current Space Shuttle environment.

STAGE-AND-ONE-HALF APPROACH

The stage-and-one-half concept illustrated in Fig. 2-2 utilizes the ICD engine modified to a fixed 53:1 area ratio nozzle and large external propellant tanks that contain the entire boost phase propellant load, which is expended in essentially a parallel burn



PROGRAM COSTS

TOTAL	\$9.8 B
DD T&E	7.3 B
PEAK	1.87 B
S/FLT	\$3.8 M

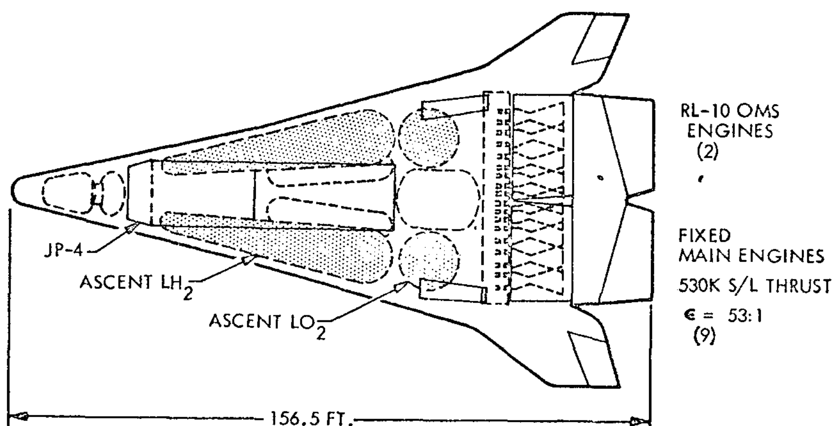
KEY ISSUES

- TOTAL COST
- PEAK FUNDING
- STAGING
- COMMON PRIMARY ENGINES
- INTEGRATED OMS/ACPS TANKS
- CONCURRENT INTERACTIVE DEVELOPMENT
- SUBSYSTEM COMMONALITY

WEIGHTS

	ORBITER	BOOSTER
DRY WT	188K	477K
P/L (POLAR)	40K	N/A
PROPELL-ASCENT	546K	2,643K
LAUNCH WT	831K	3,292K
GLOW	4,123K	

Fig. 2-1 Concurrent Two-Stage Fully Reusable Approach



PROGRAM COSTS

TOTAL	\$6.6B
DDT&E	3.6B
PEAK	0.89B
\$/FLT	\$5.6M

KEY ISSUES

- TANK COST
- STAGING CONCEPT
- OPEN OCEAN TANK IMPACT
- THRUST STRUCTURE INTEGRATION
- BASE GEOMETRY
- PROPELLANT CROSSFEED
- PERFORMANCE SENSITIVITY

WEIGHTS

	ORBITER	TANKS
DRY WT	294K	112K
P/L (POLAR)	40K	N/A
PROPELL-ASCENT	239K	3,063K
LAUNCH WT	630K	3,186K
GLOW	3,816K	

Fig. 2-2 Stage-and-One-Half Approach

of all main engines at liftoff. Engines are cut off during ascent, with orbit injection on two or three engines after external tank staging. Advanced technology is applied throughout in a single-thread development approach that attains low recurring cost per flight with low DDT&E cost, total cost, and peak funding, making this concept a feasible alternative.

Section 3
PHASED BOOSTER DEVELOPMENT

The four-month study extension starting 1 July 1971 and extending through the 1 September Interim Review responded to the TD-3001 Guidelines summarized in Fig. 3-1. The approach to reducing peak annual funding requirements provided for introduction of external tanks to reduce orbiter size and weight to accommodate a heat sink booster, and for phased booster development using large solid rockets (SRMs) as an interim expendable booster configuration. Reduced performance requirements and reduced payload bay dimensions were considered in the three- to four-year period of interim operations. A wide range of design alternatives was evaluated in the studies reported on 1 September.

TD GUIDELINES	LMSC ASSUMPTIONS
TWO-STAGE EXTERNAL TANK ORBITER	78-MONTH OVERALL SPAN TO FMOF
INTERIM EXPENDABLE BOOSTER	TWO VEHICLES ENTER HORIZONTAL FLIGHT TEST
120 IN.SRM 40 - 60 FT P/L BAY	NO VERTICAL INCREMENTAL TEST
156 IN.SRM 12 - 15 FT P/L DIA	CRYOGENIC OMS/ACPS
45 K - 65 K DUE EAST	TWO FLIGHT TEST ORBITERS
25 K - 40 K LANDED	THREE PRODUCTION ORBITERS
DELAYED FULLY REUSABLE BOOSTER	TWO FLIGHT TEST BOOSTERS
60 FT P/L BAY	TWO PRODUCTION BOOSTERS
65 K DUE EAST	COSTS INCLUDE ENGINES AND FACILITIES
40 K LANDED	NO COMMONALITY
PARALLEL OR TANDEM STAGE CONFIGURATION	PEAK ANNUAL $ TARGET = $1.0B
HiP_C ENGINE	FINAL ASSEMBLY AT PALMDALE
FMOF 30 SEPTEMBER 1978	FLIGHT TEST AT EDWARDS AFB
ATP 1 APRIL 1972	OPERATIONS AT KSC
FHF 30 MAY 1977	
FOUR YEARS INTERIM OPERATIONS - 12 FLTS TOTAL	

Fig. 3-1 System Requirements, TD 3001, 1 July 1971

SRM Interim Booster Approach

Concepts. General parameters of the seven interim booster and four final orbiter and tank configurations considered in the phased development approach are summarized in Figs. 3-2 and 3-3. Initial emphasis in system sizing and performance studies involved tradecff studies on Level I performance requirements and the impact of reduced payload bay dimensions on orbiter size and weight, external tank propellant load, and entry performance, with staging velocity set by heat sink booster requirements for the final concept. Design alternatives included single-stage and two-stage solid boosters, and tandem and parallel staging configurations. Both hydrogen and hydrogen/oxygen external tanks were considered.

Staging Velocity. In deriving the general concepts, a tradeoff study was conducted to examine booster staging velocity as a major cost driver in the total program, as summarized in Fig. 3-4. A staging velocity of 6000 ft per sec nominal was selected to minimize impact on final system GLOW while maintaining lowest recurring cost per flight in the operational program, at some sacrifice in interim cost per flight.

PAYLOAD	OTHER ORBITER INERT	OLOW	1ST STAGE INERT	1ST STAGE PROPELLANT	2ND STAGE INERT	2ND STAGE PROPELLANT	INTERIM GLOW	INTERIM
65K	19.8K	1,071K	403K	2,433K	161K	973K	5,042K	(2) 2 STG-120 IN.
65K	19.9K	1,125K	428K	2,584K	188K	1,033K	5,358K	(2C) 2 STG-120 IN.
65K	15.5K	1,071K	292K	2,093K	163K	1,046K	4,665K	(5) 2 STG-156 IN.
65K			690K	4,065K	N/A	N/A	5,826K	(5A) 1 STG-120 IN.
65K			517K	3,585K	N/A	N/A	5,173K	(5B) 1 STG-156 IN.
65K			390K	2,351K	172K	940K	4,924K	(5D) 2 STG-120 IN.
65K	14.7K	996K	475K*	3,288K	N/A	N/A	4,759K	(5C) 1 STG-156 IN.

Fig. 3-2 Summary of Interim Concepts

Payload Bay Size. Size effects illustrated in Fig. 3-5 include system weight and cost effects as well as orbiter entry heating effects associated with planform wing loading, which is 102 psf for the 40 ft payload bay length and 70 psf at 60 ft length. Cost reduction with payload bay size is not significant in suppressing peak annual funding. Peak temperatures experienced during reentry increase at the leading edges since the radii are scaled with vehicle length, and increase on the lower surface as well. To achieve 1100 nm crossrange with the smaller vehicle, peak lower surface temperature of 2600°F is experienced, as compared with the normal 2300°F temperature in the baseline orbiter configuration. Large payload bay, 15 x 60 feet, relieves entry heating and does not increase program cost significantly.

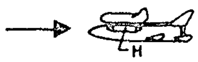
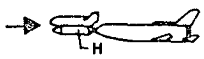
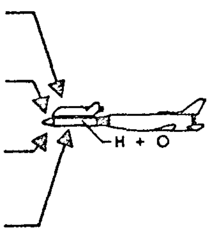
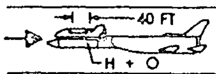
FINAL	ORBITER (DRY)	ORBITER INTERNAL PROPELLANT	DROPTANK (DRY)	DROPTANK PROPELLANT	OLOW	BOOSTER INERT	BOOSTER PROPELLANT	FINAL GLOW
	170.8K	687K	17.1K	111.3K	1,071K	453K	1,796K	3,320K
	170.4K	720K	33.1K	116.7K	1,125K	554K	2,015K	3,694K
	136.5K	16.7K	50.4K	786.6K	1,071K	477K	1,792K	3,339K
	122.9K	15.6K	47.0K	730.9K	996K	454K	1,586K	3,036K

Fig. 3-3 Summary of Final Concepts

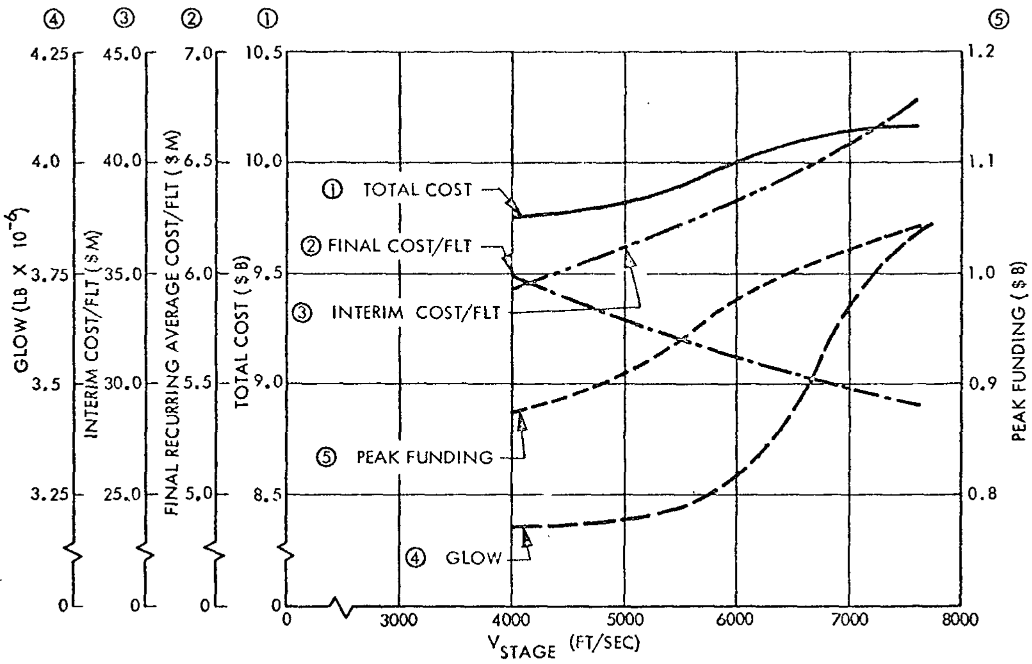
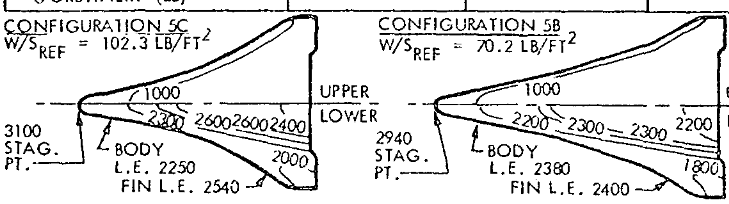


Fig. 3-4 Program Cost Impact of Staging Velocity

PARAMETER	COMPARATIVE DATA		COMMENTS
CONFIGURATION	40 FT 5C H + O	60 FT 5B H + O	BOTH ARE DESIGNED TO CARRY 65K PAYLOAD SMALL P/L BAY LENGTH IMPACT: • EXCESSIVE REENTRY HEATING • DELTA BODY SHAPE IS ALTERED • SLIGHTLY REDUCED ORBITER WEIGHTS AND COSTS IMPORTANT, BUT NONDRIVING CONSIDERATIONS: • GLOWs, SENSITIVITIES AND TOTAL COST • AERO AND STABILITY FACTORS
ORBITER			
BODY LENGTH (FT)	99.8	120	
DRY WEIGHT (KLB)	122.9	136.5	
WING LOADING-P/L IN (PSF)	102.3	70.2	
LANDING SPEED			
P/L OUT (KT)	150	150	
P/L IN (KT)	124	120	
OLOW (KLB)	996.0	1,070.6	
SYSTEM			
INTERIM GLOW (MLB)	4.759	5.173	
FINAL GLOW (MLB)	3.036	3.339	
TOTAL PROG. COST ($ B)	9.873	10.116	
PEAK ANN. FUND ($B)	.956	.972	
FINAL AVE. RECUR ($ M)	5.54	5.69	
$\frac{\partial GLOW\ (LB)}{\partial ORB.INERT\ (LB)}$	22	28	



NOTE:
HEATING COMPUTED USING NASA THERMO PANEL RECOMMENDED TECHNIQUES

TEMPERATURE IN °F
(ϵ = 0.8)

Fig. 3-5 Effect of Payload Bay Size

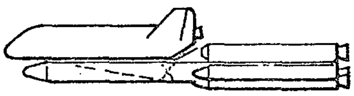
Tandem vs Parallel Configuration. The significant aspects of staging configuration summarized in Fig. 3-6 are the external tank weight and cost, booster weight effects of nose loading, and the booster nose cap interference in the tandem configuration. When both liquid hydrogen and liquid oxygen are carried externally, the hydrogen tank must be stiffened to carry the increased loads from the liquid oxygen regardless of the staging configuration. The single tank tandem configuration turns out to be lighter by 6000 lb, and less costly by $120 million over the operations span. This weight advantage is partially offset by a booster weight increase to accommodate additional loads. A feasible design approach for the translating booster nose cap is illustrated in Fig. 3-7.

INTERIM

PARALLEL

DISADVANTAGES

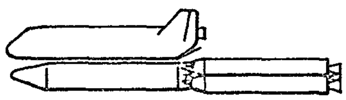
- REQUIRES TWO SIDE-MOUNTED TANKS
- INCREASES ORBITER LOADS AND ORBITER WEIGHT
- MORE COMPLEX TANK STAGING
- MORE DIFFICULT BOOSTER/ORBITER ABORT SEPARATION BECAUSE OF BERNOULLI EFFECT
- HIGHER COST AND RISK SYSTEM



TANDEM

ADVANTAGES

- SINGLE LOWER COST TANK
- LIGHTER LOWER COST ORBITER
- SIMPLER TANK STAGING
- SIMPLER BOOSTER/ORBITER SEPARATION
- LOWER SYSTEM COST AND RISK
- BETTER ASCENT CG TRACKING

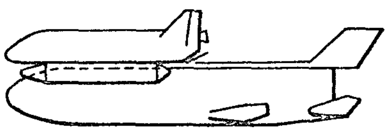


COMMON

- ASCENT FLOW FIELD AND LOCAL LOADS
- PRIMARY LOAD PATHS
- SEPARATION AND STAGING
- ASCENT HEATING
- ADAPTER STRUCTURE

FINAL

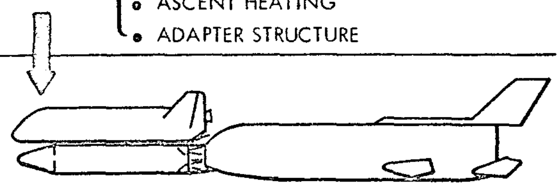
PARALLEL



ADVANTAGES

- LOWER BOOSTER LOADS

TANDEM



DISADVANTAGES

- MORE COMPLEX BOOSTER ATTACH ARRANGEMENT
- HIGHER BOOSTER LOADS

Fig. 3-6 Parallel vs Tandem Configurations

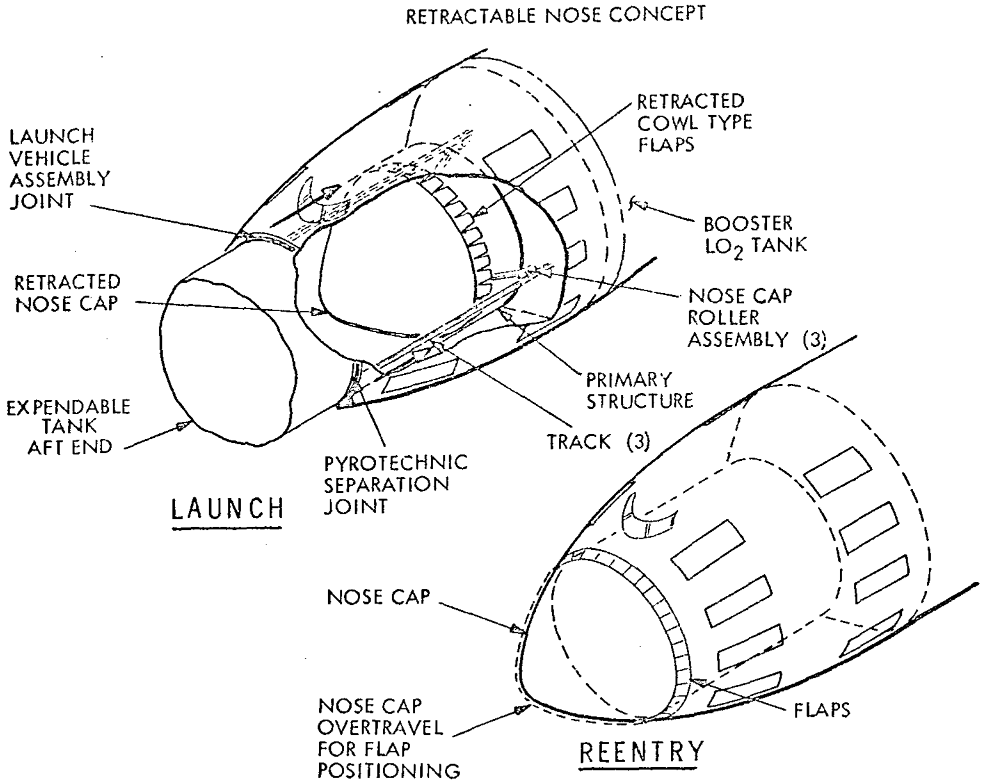
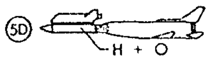
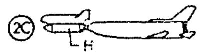


Fig. 3-7 Tandem Booster-Orbiter Separation

H vs H/O. The external tank arrangements compared in Fig. 3-8 in the final configuration show some significant differences in size, weight, and cost effects. The main advantage of external hydrogen only is in the tank cost which is reflected in lower recurring cost per flight. This advantage is offset by the development flexibility achieved with all propellants external in terms of development phasing and decoupling the orbiter from staging velocity changes. An external H/O tank is the best arrangement for the preferred tandem staging configuration and is the concept selected for further studies.

Interim Booster Selection. Having progressively narrowed the design options to an H/O external tank arrangement with tandem staging configuration and the full 15 ft by 60 ft payload bay, the matrix of candidate interim boosters with a single orbiter and external tank concept is arranged schematically in Fig. 3-9. Resolution of technical issues and program cost aspects in detail for SRM boosters involves considerable engineering analysis, as summarized in Fig. 3-10. The individual

	CONFIGURATION	
	ORBITER	
120	BODY LENGTH (FT)	137
136.5	DRY WEIGHT (KLB)	170.4
16.7	INTERNAL PROP WT (KLB)	720
	EXTERNAL TANKS	
21 x 124	SIZE DIA, & LENGTH (FT)	22 x 110
50.4	DRY WT (KLB)	33.1
786.6	PROP WT (KLB)	116.7
210	DEVELOP COST ($M)	181
+9 MO.	DEVELOP SCHEDULE	
	TOTAL SYSTEM	
4.924	INTERIM GLOW (MLB)	5.358
3.339	FINAL GLOW (MLB)	3.694
10.064	TOTAL PROG. COST ($ B)	10.144
.976	PEAK ANN. FUND ($ B)	1.021
35.2	INTERIM AVE. RECUR. ($M)	35.1
5.68	FINAL AVE. RECUR. ($ M)	5.16

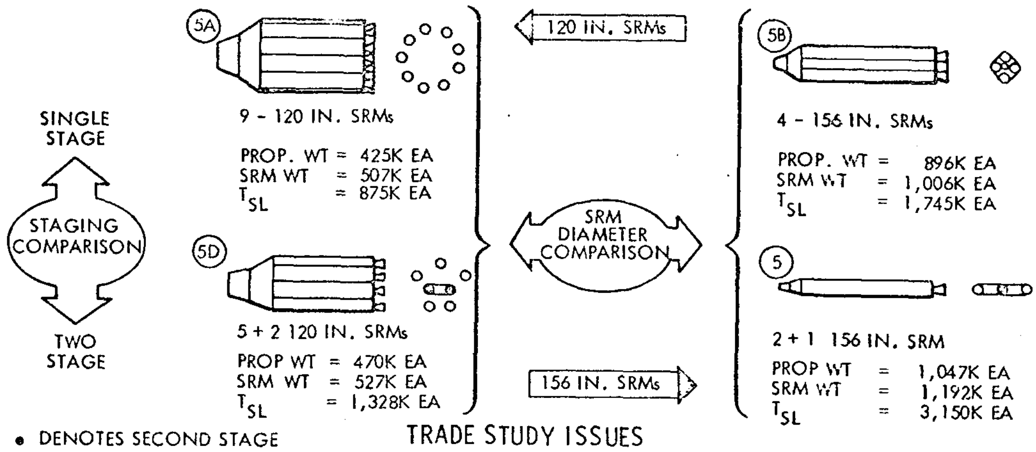
ADVANTAGES

- REQUIRES SMALLER ORBITER
- DECOUPLES ORBITER FROM STAGING VELOCITY AND MISSION VELOCITY
- REDUCES PEAK ANNUAL FUNDING
  DIFFERENCE ≈ $45M
- REDUCES SYSTEM GLOW
  DIFFERENCE ≈ 430 KLB
- REDUCES TOTAL PROGRAM COST
  DIFFERENCE ≈ $80M

ADVANTAGES

- REQUIRES SMALLER TANK
  33 KLB VS 51 KLB
- PROVIDES LOWER RECURRING COST/FLIGHT
  DIFF. ≈ $500K/FT

Fig. 3-8 External Tank Arrangement

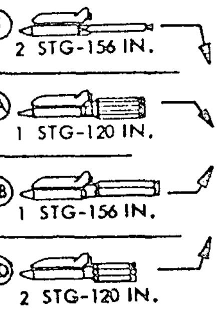


TRADE STUDY ISSUES

- PERFORMANCE/WEIGHTS
- AERO STABILITY AND TVC
- STAGING/SEPARATION
- ABORT REQ./THRUST TERMINATION
- ACCOUSTICAL ENVIRONMENT
- POLLUTION
- FACILITIES
- GROUND OPERATIONS
- SRM DEV. RISK
- SYSTEM COST

Fig. 3-9 SRM Booster Concepts

SRM DIA/ NO. SRMs	PROPELLANT/ SRM WT	SRM DEV. RISK	NO. STAGES/ SEPARATED UNITS	INTERIM BLOW	INTERIM GLOW	CONTROL REQ. δ_c/δ_c	SRM DEV COST ($M)	SRM PROD. COST ($M)	NONRECURRING DEL. COST ($M)	STAGE DEV COST ($M)	INTERIM PROG COST ($M)	INTERIM COST PER FLIGHT ($M)	TOTAL PROG. COST ($M)	PEAK FUNDING ($M)	
156 IN/3	1,047 K/ 1,192 K	LOW RISK	2/3	3,590 K	4,660 K	2.5/ 3.5	66	134	15.0	51	387	32.2	10,119	967	(5) 2 STG-156 IN.
120 IN./9	452 K/ 507 K	LOWEST RISK	1/1	4,750 K	5,830 K	2.5/ 2.0	33	212	5.0	30	468	39.0	10,080	987	(5A) 1 STG-120 IN.
156 IN./4	896 K/ 1,006 K	LOW RISK	1/1	4,100 K	5,170 K	4.5/ 2.5	62	154	15.0	32	408	34.0	10,116	972	(5B) 1 STG-156 IN.
120 IN./7	470 K/ 527 K	LOWEST RISK	2/5	3,850 K	4,920 K	3.5/ 2.5	33	172	5.0	58	423	35.2	10,064	976	(5D) 2 STG-120 IN.



120 IN. D VS 156 IN. ISSUE

- 156 IN. DIA ALLOWS FEWER SRMs
- 156 IN. RESULTS IN LOWER GLOW AND PROGRAM COST
- 156 IN. LEAST COMPLEX STAGE DESIGN

SINGLE VS TWO-STAGE ISSUE

- SINGLE IS LESS COMPLEX
- TWO-STAGE HAS HI-Q 1st SEPARATION
- TWO-STAGE REQ MULTIPLE UNIT SEPARATIONS

RECOMMENDATION

- SELECT 156 IN. DIA
- SELECT SINGLE STAGE

Fig. 3-10 Selection of Interim Booster Configuration

cost differences apparent at motor and stage development level wash out in the total program cost comparison so that the selection rationale is primarily on the basis of relative complexity. The designers' choice is the 5B single-stage 156-in. cluster of four motors integrated into a unit under the tandem load-bearing external tank.

Recommended Approach. Cost and schedule characteristics of the baseline program with four years of interim operations at three flights per year, followed by a buildup to the 445 flight mission model, are shown in Fig. 3-11. The phased interim SRM booster approach suppresses peak annual funding to the target $1.0 billion level in a two-peak-funding profile with total program cost of $10.7 billion, adjusted from the tradeoff study data of Fig. 3-10 to reflect the most recent revisions in guidelines and requirements. The influence of orbiter development phasing that delays FHF to mid-1977 in the interest of suppressing initial peak funding severely constrains the horizontal flight test program against a fixed FMOF, and introduction of an interim booster

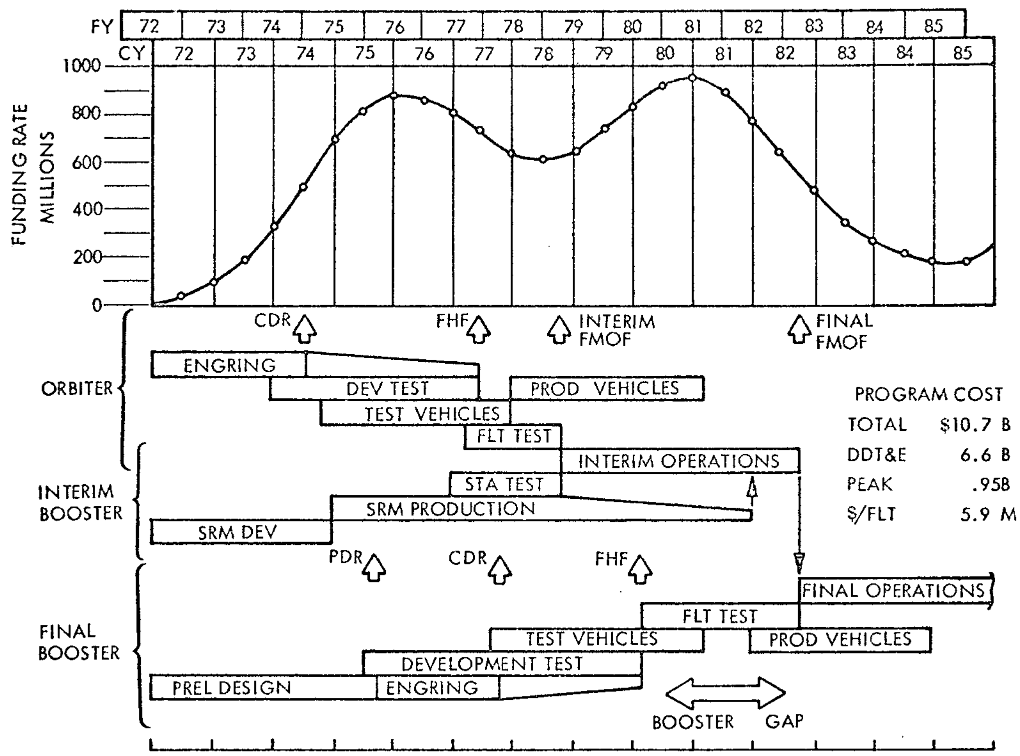


Fig. 3-11 Baseline Program Characteristics

configuration may require additional integrated stage manrating flight tests not provided for in the restricted schedule spans. Failure to achieve significant technical objectives during this critical time period at a high funding level may increase risks of incurring remedial DDT&E costs for engineering changes and requalification tests, and may delay production of the final booster. A suggested adjustment in this program alternative is to level the workforce and funding profile by accelerating the final booster go-ahead about one year and adopting a phased orbiter approach in some subsystems and final assembly operations.

Section 4
PHASED ORBITER DEVELOPMENT

The study of phased orbiter development for the MSC 040A Mark I/Mark II concept, which was initiated following the 1 September Interim Review, responded to the guidelines and requirements of TD 3003 listed in Fig. 4-1. In this approach, reduction in peak annual funding by phased development of the orbiter subsystems and primary engines is provided to permit concurrent development of the booster. Reduced performance requirements and state-of-the-art engines and avionics, for example, characterize the Mark I concept, with growth in subsystem sophistication and Mark II performance capability within a fixed airframe design.

TD GUIDELINES

MARK I/MARK II ORBITER DEVELOPMENT
EXTERNAL H/O TANKS - 15 BY 60 FT P/L BAY
CONCURRENT LOX/RP BOOSTER
CONCURRENT PFB BOOSTER
PRIMARY ENGINE ALTERNATIVES

MARK I		MARK II
J-2	→	HiP_C
J-2S	→	HiP_C
J-2	→	J-2
J-2S	→	J-2S
HiP_C	→	HiP_C

STORABLE OMS/ACPS
40K POLAR/65K DUE EAST P/L
ATP ___ 1 JUNE 1972
FHF ___ 30 JUNE 1976
FMOF ___ MARK I 30 SEPTEMBER 1978
___ MARK II 30 SEPTEMBER 1983

LMSC ASSUMPTIONS

2 MARK I FLIGHT TEST ORBITERS
3 MARK II PRODUCTION ORBITERS
4 LOX/RP BOOSTERS
76-MONTH SPAN TO FMOF
DELTA-WING MSC 040A CONFIGURATION
OMS ΔV - 1000 FPS
STAGING VELOCITY 6000 ± 1000 FPS

Fig. 4-1 System Requirements – TD 3003 – 14 September 1971

Mark I/Mark II Approach

<u>Concepts</u>. The orbiter and integrated vehicle configuration, Fig. 4-2, incorporates the MSC 040A delta-wing orbiter with a reusable flyback LOX-RP booster in the tandem nose loaded configuration. The external orbiter tank carries 865K lb of ascent propellants in a LOX-forward arrangement. Based on previous tradeoff studies, staging velocity was set at 6000 fps nominal, and emphasis in this period of study was on engine selection tradeoffs and subsystems definition. A basic aluminum airframe, Fig. 4-3, was defined in the continuing refinement of structures and weights analysis, and typical subsystem arrangements are indicated in Fig. 4-4.

<u>Primary Engine Selection</u>. Sensitivity of orbiter design to staging velocity and installed engine thrust is characterized in Fig. 4-5 by design delta-V and liftoff thrust-to-weight ratio. As either staging velocity or thrust-to-weight ratio decreases, the required nominal delta-V to injection orbit increases. The data shown reflect ascent requirements into a 50 by 100 nm due east orbit, and the region in which engine-out abort to orbit becomes unattainable is indicated. Significantly higher minimum thrust-to-weight ratio is required for engine-out abort into polar orbit.

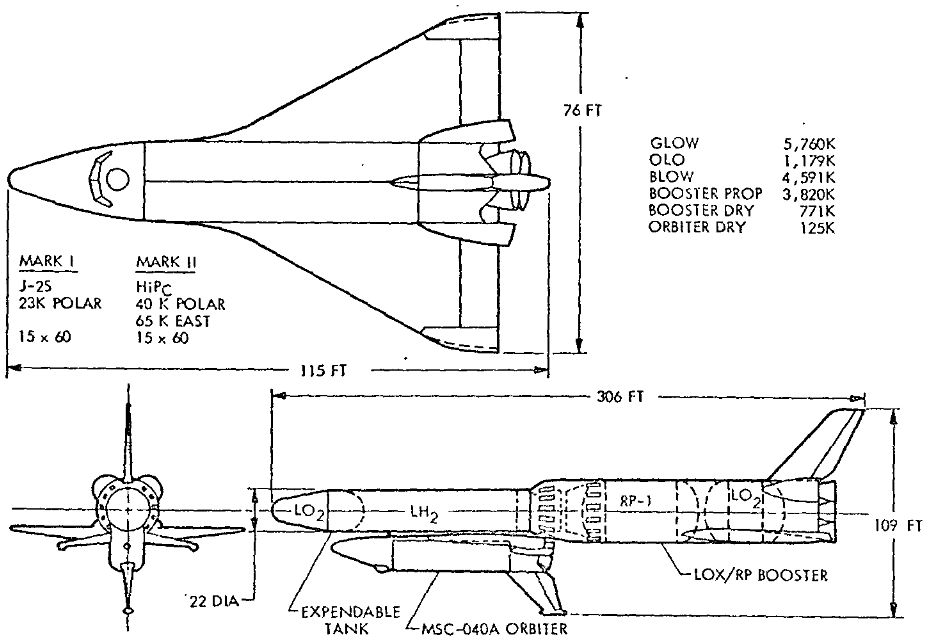


Fig. 4-2 Orbiter and Integrated Vehicle Configuration

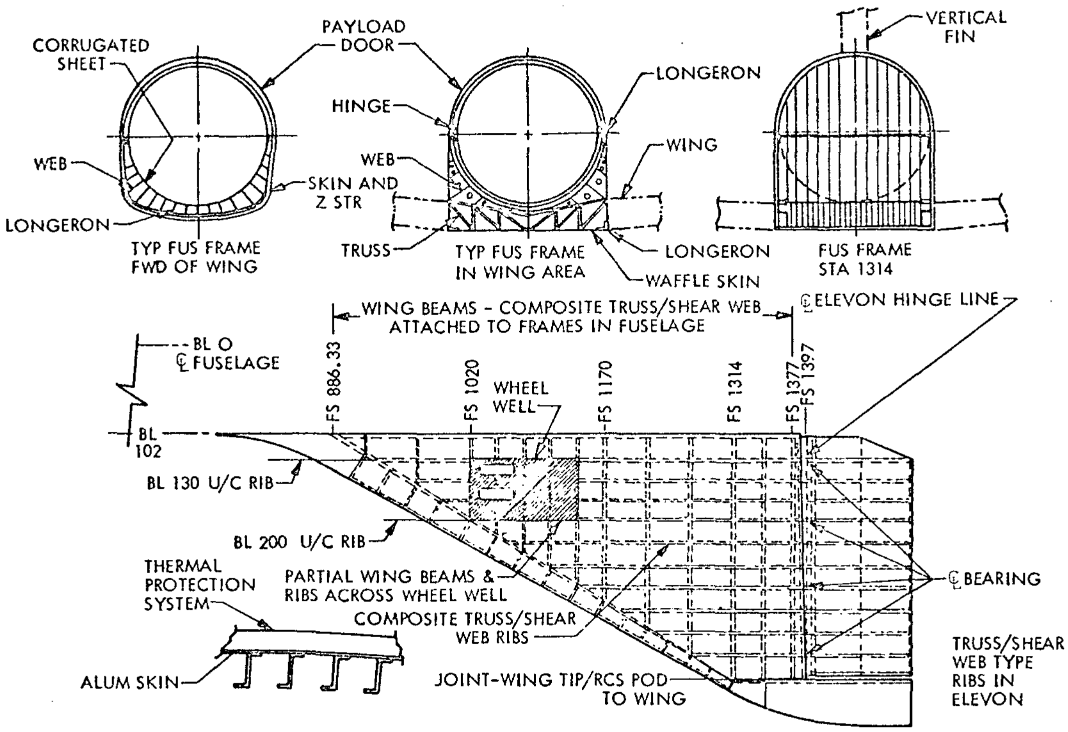


Fig. 4-3 Typical Aluminum Airframe

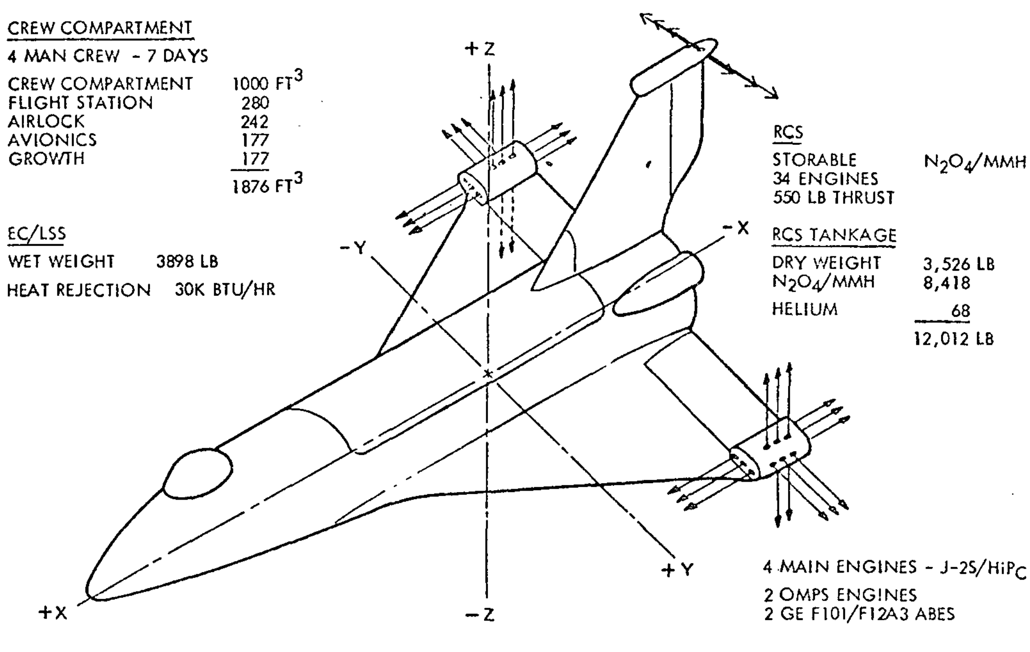


Fig. 4-4 Typical Subsystems

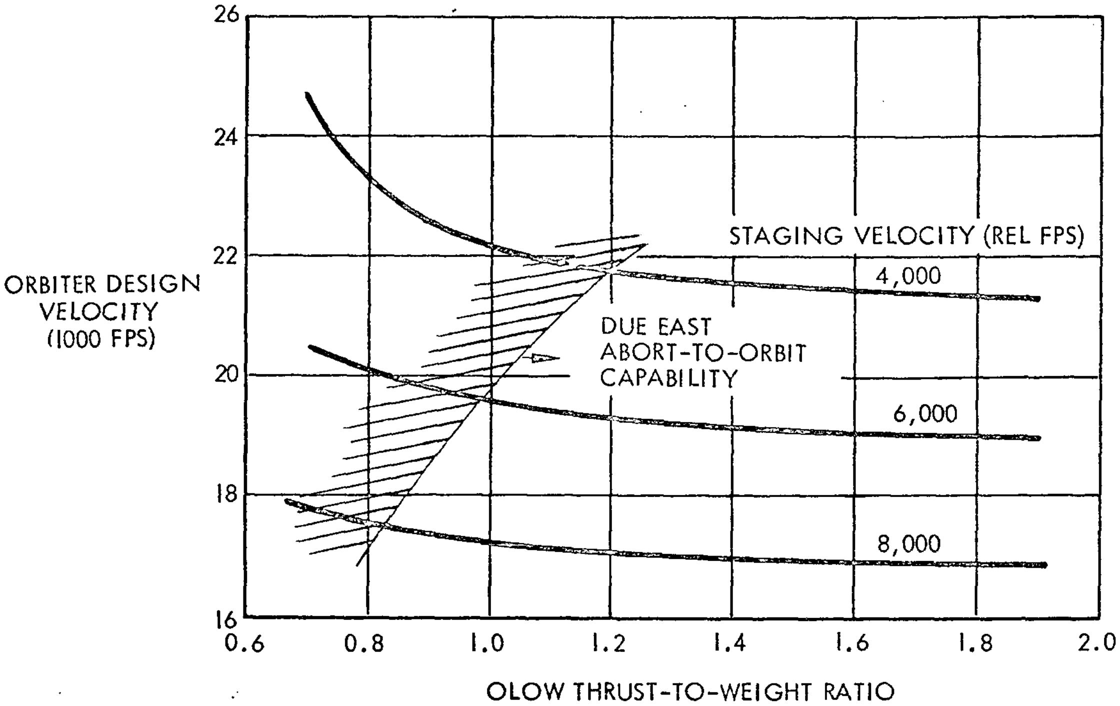


Fig. 4-5 Engine Selection and Tank Sizing Parameters

The influence of engine envelope on installation constraints, Fig. 4-6, was examined for each of the candidate engine designs indicated in Fig. 4-7. Extension of the gimbal dynamic envelope beyond the orbiter fuselage moldlines is not a limiting condition, since canted nozzle operation is acceptable if cant angles are not large. The characteristic HiP_c rocket engine length is greater than its J-2/J-2S counterpart at the same thrust level and has a smaller diameter. Thus, a HiP_c rocket engine, which is sized to match the thrust level of a J-2/J-2S, can fit within boundaries established by landing clearance and reentry flow fields.

In Fig. 4-7, the J-2 and J-2S versions and two thrust levels of the high-pressure engines have been grouped by characteristics. The changes shown to the J-2 or J-2S engines, respectively, allow accomplishment of the indicated thrust and specific impulse. The engines in the shaded regions do not satisfy spacing constraints imposed by the base area of the O4OA vehicle.

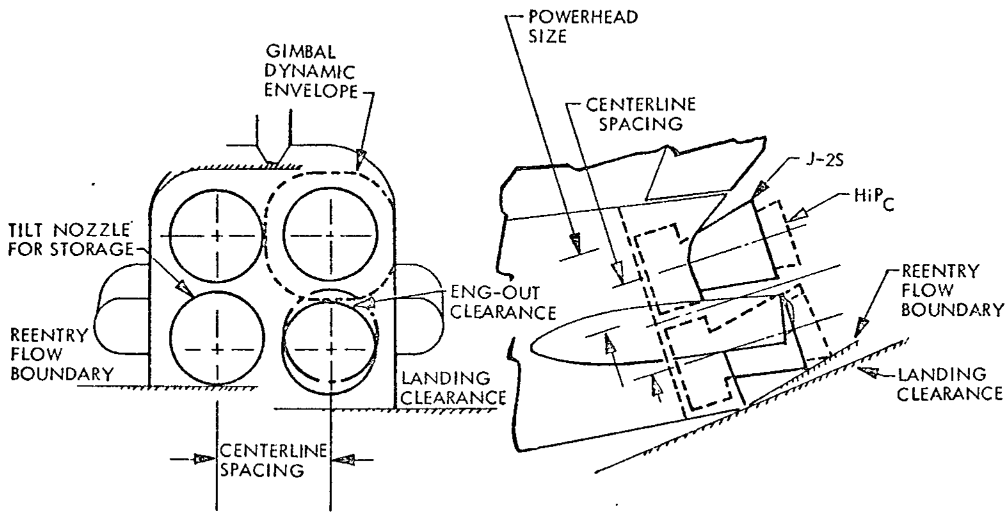


Fig. 4-6 Influence of Engine Envelope on Installation

ENGINE DESIGNATION	ALTER-NATIVE	P_c (PSIA)	ϵ	F_{VAC} (KLB)	$I_{SP_{VAC}}$ (SEC)	WEIGHT (LB)	MAXIMUM DIA/LNGTH (IN.)	ENGINE DEV. COST (M $)
J-2	BASIC	780	27.5	230.0	425.0	3450	80/120	22
J-2S	BASIC	1250	40.0	265.0	436.0	3800	80/120	82
J-2 (1)	+ $\Delta\epsilon$	780	34.0	232.2	429.0	3744	91/144	28
J-2S (A-1)	+ $\Delta\epsilon$	1250	80.0	272.5	448.3	3755	112/176	106
J-2S (A-2)	+ $\Delta\epsilon$	1250	105.0	275.0	452.8	3855	128/200	108
	1.22 X P_c BASIC							
J-2S (B-1)	-	1520	40.0	320.0	434.5	4120	80/120	107
J-2S (B-2)	+ $\Delta\epsilon$	1520	80.0	327.5	446.8	4040	112/176	137
J-2S (B-3)	+ $\Delta\epsilon$	1520	105.0	330.0	451.4	4200	128/200	139
HiP_C (TYP)	NEW DEVELOP-MENT	~3000	90	261	456	2800	75.5/148	444
		~3000	90	320	456	3700	82 /160	511

ENGINES DO NOT SATISFY 040A INSTALLATION

Fig. 4-7 Description and Grouping of Engines By Characteristics

The engine development costs to bring the engines up to Mark I status were obtained from data supplied by NASA-MSFC. It is known that these estimates do not include increasing the allowable inlet pressure requirements.

The system performance and cost trends/involved in a J-2/J-2S conversion to HiP_c engines, in terms of Mark I performance of a system sized for the HiP_c Mark II are shown in Fig. 4-8. The selection of a HiP_c thrust level, when considerations must be given to Mark I and Mark II capabilities, involves the trade of performance and cost. The formulation logic selected is to size external tanks for the 65K lb payload due east using a HiP_c engine, and then, with the tanks fixed, determine the payload delivery capability of the Mark I system with J-2 and J-2S engines. As HiP_c thrust level is increased, the improved system performance results in reduction in Mark I payload attributed to the larger thrust level differences between the Mark I and Mark II systems.

To accomplish the stated minimum 10K lb polar payload using the J-2 Basic engine for Mark I, the HiP_c thrust level must be below 220K lb. In the case of the J-2S Basic engine, the maximum allowable HiP_c thrust level becomes 400K lb.

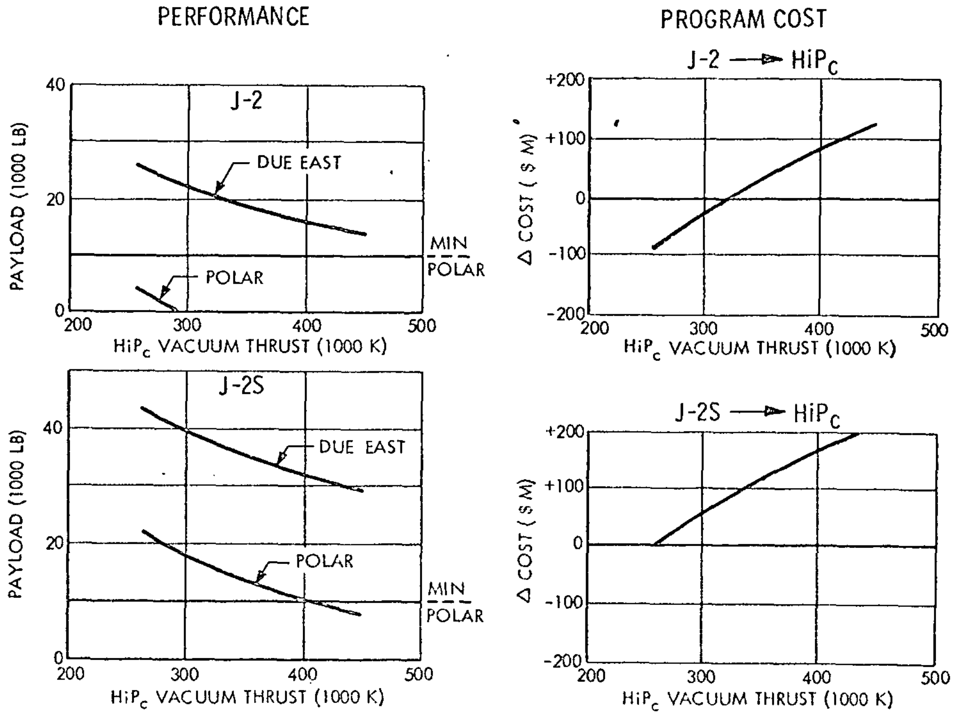


Fig. 4-8 Mark I/Mark II Cost and Performance Trends

The major issue in cost becomes the HiP_c thrust selected because of the relative insensitivity of cost to exterior tank size. An evaluation of the factors listed in Fig. 4-9 suggest that only the J-2S Mark I option for conversion to a HiP_c Mark II orbiter configuration should be considered, and this arrangement is taken as the baseline for further comparison of engine selection options.

Options for a straight-through development approach using either J-2 or J-2S in a single-thread Mark II configuration depend upon thrust-to-weight ratio effects and external tank size effects that influence cost in addition to the engine cost variables among the various engine candidates. The performance characteristics are summarized in Fig. 4-10. These systems are characterized by low ignition thrust-to-weight ratios and large external propellant tanks determined by the Mark II performance requirements. The most favorable performance for an engine compatible with the MSC-040A base geometry is the J-2S/B-1. The cost comparisons in Fig. 4-11 indicate substantial savings in total program cost, including both tank and engine cost impact, with a single-thread application of either J-2 or J-2S engines; $200 million for the recommended J-2S/B-1 configuration. The basic J-2/J-2S engines have

FACTS:

- J-2 AND J-2S HAVE DEMONSTRATED THRUST, I_{SP}; AVAILABLE FOR MARK I
- J-2 AND J-2S NEED REDESIGN FOR HIGHER INLET PRESSURES, AND ARE SENSITIVE TO INSTABILITY RESULTING FROM START PRESSURE FLUCTUATIONS
- J-2 AND J-2S BASIC COSTS ARE RELATIVELY WELL KNOWN; OPERATING COSTS ARE NOT
- NEITHER J-2 NOR J-2S IS DESIGNED TO BE REUSABLE
- THE REUSABLE HiP_C ENGINE WILL UTILIZE NEW TECHNOLOGY
- CHANGE TO HiP_C IS NOT SIMPLE PLUG-IN
- J-2 PERFORMANCE DOES NOT MEET MINIMUM MARK I PAYLOAD REQUIREMENT

OPINIONS:

- EARLY AVAILABILITY OF J-2/J-2S DECREASES RISK
- J-2 AND J-2S MINIMUM LIFETIMES ARE KNOWN
- HiP_C PROGRAM COST SUBJECT TO NUMEROUS VARIABLES
- HiP_C INCREMENTAL COMPONENT DEVELOPMENT APPROACH MAY INCREASE COSTS

Fig. 4-9 Mark I J-2/J-2S Conversion to HiP_c Mark II

65K - DUE EAST V_{ST} = 6000 FPS

MARK II ENGINE	T/W	EXTERNAL TANK PROPELLANT (10^6 LB)	OLOW (10^6 LB)
J-2 BASIC	0.64	1.15	1.44
J-2S BASIC	0.80	1.04	1.33
J-2 OPT 1	0.66	1.12	1.41
J-2S/A-1	0.89	0.94	1.23
J-2S/A-2	0.91	0.93	1.21
J-2S/B-1	1.0	1.0	1.29
J-2S/B-2	1.09	0.92	1.20
J-2S/B-3	1.12	0.90	1.18

ENGINES DO NOT SATISFY 040A INSTALLATION

Fig. 4-10 J-2/J-2S Single-Thread Mark II Performance Characteristics

ENGINE	TANKS N.R.	TANKS REC.	ENGINE N.R.	ENGINE REC.	TOTAL N.R.	TOTAL REC.	TOTAL	DELTA FROM BASELINE ($M)
BASELINE *					693	776	1469	
J-2 BASIC	209	607	22	257	231	864	1095	-374
J-2S BASIC	204	582	82	350	286	940	1226	-243
J-2 OPTION 1	208	603	28	260	236	863	1099	-370
J-2S A-1	198	549	106	385	304	934	1238	-231
J-2S A-2	198	542	108	385	306	927	1233	-236
J-2S B-1	202	566	107	393	309	959	1268	-201
J-2S B-2	197	538	137	400	334	938	1272	-197
J-2S B-3	191	533	139	400	330	933	1263	-206

* BASELINE J2S → HiP_C COST – ($MILLIONS)

Fig. 4-11 J-2/J-2S Single-Thread Mark II Cost Comparisons

demonstrated performance, and basic costs are relatively well known. These engines, however, are sensitive to instability resulting from start pressurization transients and need some redesign for higher inlet pressures. Neither engine is designed for reusability, and the preferred J-2S engine for single-thread Mark II development may incur higher development costs than those used as the basis for this evaluation.

Similar evaluation of the HiP_c engine in a single-thread Mark II orbiter development with engine thrust level as the main parameter shows that orbiter weight variations are largely offset by reduction in velocity losses as orbiter thrust level is increased; therefore external tank propellant requirements show low sensitivity to thrust level selection. Evaluation factors listed in Fig. 4-12 suggest that a more refined development risk and schedule risk assessment for the pacing HiP_c engine development is necessary before a decision on this alternative can be made.

FACTS

- HiP_C ENGINE WILL UTILIZE NEW TECHNOLOGY
- ENGINE WILL BE DESIGNED FOR REUSABILITY
- SUBSYSTEM CHANGES NOT NECESSARY BETWEEN MARK I/MARK II
- HiP_C HAS ONLY BEEN THROUGH COMPONENT DEVELOPMENT
- DEVELOPMENT PROGRAMS ARE BASED ON EXPERIENCE IN LOW-PRESSURE ENGINE PROGRAMS
- HiP_C COSTS ARE EXTRAPOLATED FROM LOW-PRESSURE PROGRAMS

OPINIONS

- OPERATIONAL COSTS SHOULD BE LOWER THAN J-2 OR J-2S
- HiP_C SCHEDULE PROVIDES LITTLE SLACK FOR MARK I FMOF WHICH MAY INCREASE RISK

Fig. 4-12 HiP_c for Mark I/Mark II

The engine program selection rationale, developed from the parameters indicated in Fig. 4-13, considers effects of total program cost, performance sensitivity, and peak annual funding, in relation to the baseline J-2S Mark I conversion to the HiP_c Mark II configuration. The J-2 conversion to HiP_c has severe limitations in Mark I performance, and as a straight-through Mark II development shows very high sensitivity partial of GLOW-to-orbiter weight growth. These considerations appear to eliminate the J-2. The HiP_c straight-through development impacts peak annual funding, although total program cost is lower this way because of the single-thread approach. The baseline J-2S Mark I conversion to HiP_c Mark II is the selected approach, with the J-2S single-thread Mark II development retained in the study as an option. The baseline approach offers increased performance, abort-to-orbit capability, early availability of a Mark I engine, and assured reusability and growth potential for the Mark II orbiter program.

ABORT TO ORBIT NOT CONSIDERED

OPTION	RELATIVE COST ($ MILLIONS)	ENGINE PROGRAM RISK	SYSTEM SENSITIVITY ∂ GLOW/ ∂ ORBITER WEIGHT	MARK I PAYLOAD	EFFECT ON PEAK ANNUAL FUNDING ($ MILLIONS)
J-2 → HiP_c	-100	MODERATE	-	5000 LB POLAR 27K DUE EAST (250K Hi Pc)	-18
J-2S → HiP_c	BASELINE	MODERATE	-	23,000 LB POLAR 45K DUE EAST (250K Hi Pc)	0
J-2 $\xrightarrow[\text{ENGINE}]{\text{SAME}}$ J-2	-374	LOW TO MODERATE	153	40K POLAR 65K DUE EAST	-15
J-2S $\xrightarrow[\text{ENGINE}]{\text{SAME}}$ J-2S	-243	LOWEST	72	40K POLAR 65K DUE EAST	-15
HiP_c $\xrightarrow[\text{ENGINE}]{\text{SAME}}$ HiP_c	-150	HIGHEST	55	40K POLAR 65K DUE EAST	+100

Fig. 4-13 Engine Program Selection

Recommended Approach. The cost and schedule characteristics of the baseline program for a Mark I/Mark II phased orbiter development approach are summarized in Figs. 4-14 and 4-15, using the guidelines of TD 3003 and TD 3004, which provide for a concurrent LOX-RP flyback booster and a five-year span between Mark I and Mark II orbiters.

For Mark I operations, the orbiter uses the J-2S engine and phases over to a HiP_c 261K lb thrust engine for Mark II. The booster uses the F-1 engine for both Mark I and Mark II operations. Costs for the J-2S and F-1 engines were obtained from MFSC. For these estimates, a 7-1/2 percent fee was subtracted from the original data to make them consistent with all other estimates. Estimates of booster DDT&E and recurring production costs were also obtained from MSFC and are based on Boeing Company data.

	MARK I 123 FLTS				MARK II 322 FLTS				445 FLTS
	DDT&E	REC. PROD.	REC. OPS.	TOTAL	DDT&E	REC. PROD.	REC. OPS.	TOTAL	PROGRAM TOTAL
ORBITER	1,470	29	312	1,811	281	287	180	748	2,559
EXTERNAL TANKS	1,156	0	44	1,200	104	346	114	564	1,764
BOOSTER	180	0	167	347	0	0	328	328	675
MAIN ENGINES	110	0	215	325	384	51	350	785	1,110
ORBITER	(74)	0	(91)	(165)	(384)	(51)	(26)	(461)	(626)
BOOSTER	(36)	0	(124)	(160)	(0)	(0)	(324)	(324)	(484)
FLIGHT TEST	149	0	0	149	0	0	0	0	149
OPERATIONS	121	0	612	733	52	0	1,170	1,222	1,955
MANAGEMENT & INTEGRATION	315	3	117	435	84	70	186	340	775
TOTALS	3,501	32	1,467	5,000	905	754	2,328	3,987	8,987

* NUMBERS IN PARENTHESES REPRESENT NASA-MSC DATA

Fig. 4-14 Baseline Program Costs ($M)

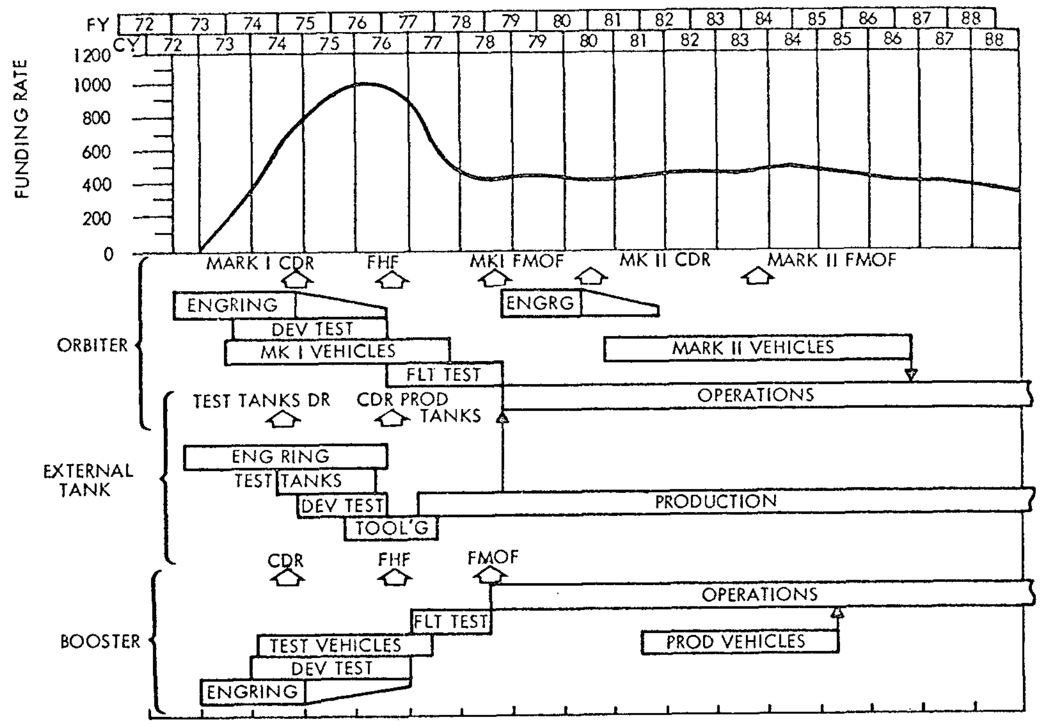


Fig. 4-15 Baseline Schedule Characteristics

The Mark II orbiter DDT&E estimate of $1470 million includes two flight test vehicles which later become the two Mark I operational vehicles. The $29 million of Mark I recurring production cost is the cost to retrofit these vehicles to Mark I operational status. The $287 million Mark II recurring production cost includes retrofitting the two Mark I orbiters to the Mark II configuration plus the production of three additional Mark II orbiters. No recurring production cost is shown for Mark I boosters, for these are assumed to be covered as two flight test boosters under the $1156 million of booster DDT&E. The Mark II booster recurring production cost of $346 million includes the cost of retrofitting the two Mark I boosters to the Mark II configuration plus the production of two additional Mark II boosters.

Detailed program definition master schedules and supporting subsystem development schedules have been prepared for the Mark I/Mark II baseline program. As shown in the highly compressed schedule and funding profile in Fig. 4-15, the annual funding requirements peak in FY 1976 at $991 million. The characteristics of this concurrent booster development approach differs from the phased booster development approach

shown previously, which resulted in a second annual funding peak slightly higher than the first. In analyzing the funding benefits of phased subsystem development, suppression of peak costs appears to derive from phasing of engineering development activity and test hardware rather than from production hardware phasing.

Rather than risk costs for deactivation and reactivation of orbiter production for Mark II, it appears preferable to pull the Mark II airframe production forward and thereby maintain a level workforce, and perhaps provide a cushion for the buildup of payload costs that begin with the traffic model buildup in FY 1979. Additional cost benefits are projected for tentative conclusions reached elsewhere in the study if a straight-through development sequence is considered, using the J-2S engine alone and the RSI thermal protection system. This approach would provide for manufacture of all orbiter airframes and a continuous modification program for completion of the orbiter vehicles in a configuration with full operations and performance capability according to a schedule paced by the traffic projection.